IDEA

Innovations Deserving
Exploratory Analysis Programs

*Highway Program*

# Development of a Screed to Detect and Measure Segregation of HMA Pavements

Final Report for Highway-IDEA Project 73

M. Stroup-Gardiner,
Auburn University, Auburn, AL

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TRANSPORTATION RESEARCH BOARD • THE NATIONAL ACADEMIES

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## ABSTRACT

Previous research indicated that temperature differentials can be used to establish if a hot mix asphalt (HMA) pavement is likely to have uniform material properties that can be related to pavement performance. However, it is both expensive and time consuming to have an inspector on each job evaluating temperature differentials with a handheld infrared camera. A more economical handheld infrared gun can also be used but it still requires a technician to acquire the data. The goal of this research project was to develop a prototype infrared sensor bar that can be mounted to the back of the paver that includes data acquisition and analysis software.

The prototype unit consists of a transverse line of infrared sensors, signal conditioners, and computer data acquisition system, and a global positioning system (GPS). The system and can continuously monitor temperature differentials during construction. Real time transverse temperatures are plotted on a computer screen for use by the paving crew. The software produces a summary of potentially segregated areas by level of segregation (i.e., low, medium, and high) as well as the number of paver stops over one minute for use by the state agency.

Preliminary testing with the system on existing pavement surfaces shows the system can evaluate the transverse temperature differential, the low budget GPS system is reasonably accurate over multiple runs for locating pavement anomalies, the software is easy to use, and the agency report that locates all non-uniform transverse temperature areas is automatically prepared.

## INTRODUCTION

The recently completed NCHRP 9-11 Segregation in Hot Mix Asphalt Pavements (HMA) recommended the use of infrared thermography as one of two methods for specifying the detection and measurement of various levels of segregation during the construction of HMA pavements (Stroup-Gardiner and Brown, 2000). This recommendation is based on the use of a hand-held infrared camera. Several states such as Arkansas, Georgia and Washington are currently specifying a maximum range [e.g.10°C (18.8°F)] of transverse temperature as tested by a hand-held infrared gun across the back of the screed in specifications. However, both the infrared camera and gun require a technician to physically be on the project to continually evaluate this criterion. The handheld infrared gun is economical but may be fairly variable since the accuracy and repeatability of the readings depend upon the distance of the operator from the area being evaluated. The infrared camera, while producing accurate thermal images of the entire pavement mat behind the paver, is expensive. Both technician time requirements and, in the case of the camera, the initial capital investment are major roadblocks to the wide spread use of this methodology.

This project developed an easily mounted screed attachment that can be used to automatically measure the temperature across the back of the paver.

## BACKGROUND

Two types of segregation were identified in the initial literature review for NCHRP 9-11: gradation segregation and temperature segregation. Gradation segregation is the most commonly seen type and can occur as the result of aggregate stockpiling and handling, production, storage, truck loading practices, construction practices and equipment adjustments. Temperature segregation was identified in the literature as occurring as the result of differential cooling of portions of the mix on the surface of the mix in the haul truck, along the sides of the truck box, and in the wings of the paver. An additional type, aggregate-asphalt segregation, which is common in SMAs was also suggested. A general definition of segregation was formulated which encompasses all types:

> Segregation is a lack of homogeneity in the hot mix asphalt constituents of the in-place mat of such a magnitude that there is a reasonable expectation of accelerated pavement distress(es).

Areas with a *low level of segregation* will have transverse temperature differentials of between 11 and 16°C (20 and 30°C). Materials in this area will have a mix stiffness (resilient modulus) of between 70 and 90 percent of the mix in the non-segregated areas; air voids will be up to 4 percent higher. When gradation segregation is present, there will be one or more sieves that are at least 5 percent coarser than the non-segregated area with a corresponding decrease in asphalt content of between 0.3 and 0.75 percent.

Areas with a *medium level of segregation* will have a transverse temperature differential of between 17 and 21°C (32 and 40°F). Materials in this area will have a mix stiffness (resilient modulus) of between 30 and 70 percent of the mix in the on-segregated areas; air voids will be between 2 and 6 percent higher. When gradation segregation is present, there will be two or more sieves that are at least 10 percent coarser than the non-segregated areas with a corresponding decrease in the asphalt content of between 0.75 and 1.3 percent.

Areas with a *high level of segregation* will have a transverse temperature differential of greater than 21°C (40°F). Materials in this area will have a mix stiffness (resilient modulus) of less than 30 percent of the mix in the non-segregated areas; air voids will be more than 5 percent higher. When gradation segregation is present, there will be three or more sieves that are at least 15 percent coarser than the non-segregated areas with a corresponding decrease in the asphalt content of more than 1.2 percent.

## RESEARCH PROGRAM

### Objectives

The objectives of this research program were to:

- Construct a sensor bar that can be attached to the back of the paver screed so that the transverse pavement temperature can be monitored during paving.
- Develop an automated data collection and report-generating system.
- Conduct a preliminary evaluation of both the hardware and software.

## Scope

The prototype sensor bar and software was initially refined and calibrated in the laboratory with known and relatively consistent inputs (lamps and hot plates). This testing was used to establish each sensor scaling and offset value. The entire system was then fit on the back of the paver at a local paving contractors yard. The construction supervisor's input on design and required modifications was used for subsequent modifications to the mounting system.

A preliminary assessment of the affect of sensor height, vehicle speed, and GPS settings on the data and location was accomplished by mounting the sensor bars on the back of a pickup truck. This setup was used to evaluate two existing pavement test sections. Because of possible safety issues with the bar blocking egress from the back of the paver, a small paving job is needed for the final evaluation of the sensor bar, GPS system and software. However, because of time constraints this final testing could not be completed in time for this report.

# EQUIPMENT DEVELOPMENT

## Sensor Bar

### *Sensor Selection*

A web search of infrared sensors led to the selection a stainless steel self-powered of the Omega OS36-5-280-J for use on the prototype sensor bar. The field of view is 5:1. That is, for every 5 inches (127 mm) above the surface, the infrared spot diameter is 1-inch (25.4 mm). Sensors were ordered with the air purge option for use in industrial environments that may lead to the contamination of the lens. While this sensor was the most applicable for the harsh paving environment (i.,e., high temperatures, fumes, etc.), the temperature range over which the 2% accuracy rating applies is only 125 to 155°C (260 to 310°F). The only other sensor choices had ranges of 95 to 130°C (200 to 270°F), which was rejected because the upper range was too low, and the 145 to 175°C (290 to 350°F), which was rejected because the lower range was too high.

*Construction of the Sensor Bar*

The bar was designed so that it could be mounted in two halves. Six sensors were mounted on each bar at 25.4 cm (12 inches) apart. The bars were mounted on vertical risers that are clamped onto the walkway over the screed. The horizontal bar is vertically adjustable in 12.7 cm (5 inch) increments (Figure 1). This incremental adjustment distance was selected so that the infrared spot size would change by 2.54 cm (1 inch) for every vertical adjustment.

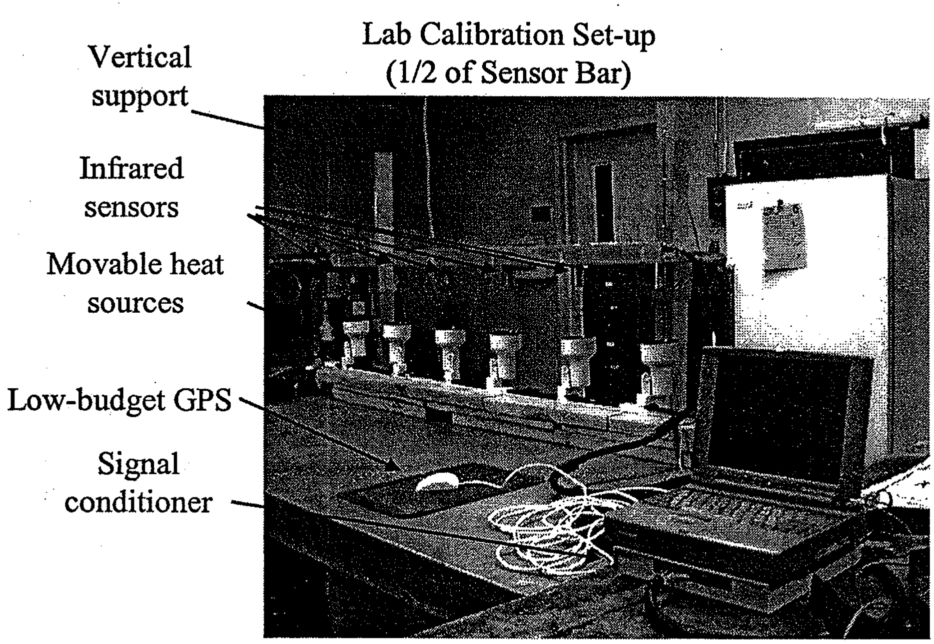



**Figure 1. Prototype sensor bar during the development phase**

The air flow requirements for the air purge system is low (Figure 2). A large scale aquarium pump with two air ports can easily provide the 10 cfm needed for each set of six sensors (one port per six sensors). The power requirements for the pump are also minimal.

Close-up of Sensor Wiring and Air Line

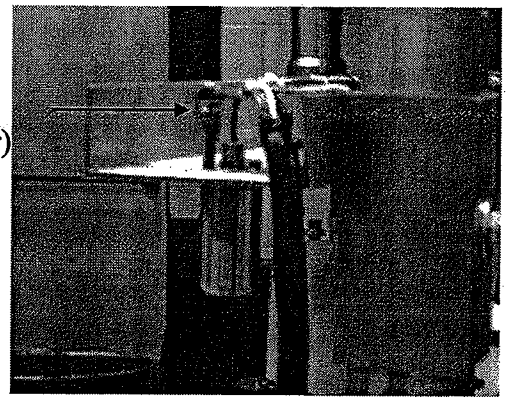



**Figure 2. Air purge connections on sensors**

*Signal Conditioning and Data Acquisition*

The J-type infrared sensors, which produce a 4 to 20 mA output, are plugged directly into a National Instruments SCC-TC-01 thermocouple input module that snaps into a National Instruments signal conditioner (SC 2345). Each conditioner can hold 8 modules; a set of two conditioners is used with 8 modules in one box and 4 in the second (only one shown in Figure 1). Data is acquired from these boxes via two National Instruments data acquisition cards that fit in the two portable computer PCMCIA slots.

*GPS*

A Garman GPS 35/36 TracPak smart antennae was selected based on its low cost and ability to locate positions within plus or minus about 3 to 10 meters (about 10 to 30 feet). This GPS unit connects directly to the portable computer with either a USB port connection (on the GPS) or through a serial port using a USB to serial port adapter. The latter was used for this project. It is powered by a 12 VDC battery and typically draws about 150 mA.

The Garman GPS 35/36 comes complete with the GPS receiver and embedded antennae. This unit can track up to 12 satellites at a time while providing 1 second updates on position after a warm up of about 15 seconds.

**Software**

LabView, a National Instruments software product, was used to write the data acquisition and report format programs. Because of the complexity of the programming needed to obtain a useful product, this programming was contracted out to Radical Systems, Inc., in Huntsville, Alabama. Figure 3 shows the setup screen initially seen by the operator. The project information, unit selection, time between measurements, temperature range for the graphical data (Figure 4), GPS drift, and sensor scale and offset values are entered on this screen.

Once this information has been entered, the operator can move to the next page (next tab on the screen) to obtain a graphical presentation of the transverse temperature (Figure 4). Figure 4 shows how the graphical presentation looks for sensors reading between 66 and 110°C (150 and 230°F). In this case, the longitudinal temperature is relatively constant (within 10°C) but is more than 10°C different transversely between the sensors (i.e., the different shades of color for each sensor).

The actual temperature measured by the individual sensors can be monitored in the upper left hand corner of this screen. However, only 6 sensors can be displayed at a time. The up and down arrows next to the temperature allow the operator to scroll through the output from all of the sensors. The distance traveled is shown on the x-axis of the graph and is computed from the GPS data. An indication of the percent of the distance traveled that is rated at each level of segregation is also shown on this screen. The actual data per sample interval (time between measurements) can be viewed on the third page (Figure 5).

The program is started by clicking on the "start paving" button at the bottom of either the setup or graphical display page, which when clicked, turns to a "stop paving" button. Once the stop paving button is clicked, the data can be saved from the setup page. Saved data can be either recalled for visual evaluation or saved as a report for the agency. This option saves the analysis as an *.htm file that is self sizing to the number of rows of data in each analysis. The *.htm file can be opened in Microsoft Word and printed out as a report. An example of this type of report is shown in Appendix C.

The agency report includes all of the project information from the setup page. It also tracks the location and number of transverse temperature measurements that meet each of the level of segregation definitions. It also includes the specific latitude and longitude locations from the GPS, the distance traveled after the start paving button is clicked, as well as the maximum, minimum and average temperature for each set of measurements. The last column indicates if the segregation is due to a paver stop. In this case, a yes is entered if the paver stops for more than one-minute and the temperature range exceeds the "no segregation" limit.

The instruction manual for the HMA Temperature Mapper program is shown in Appendix B.

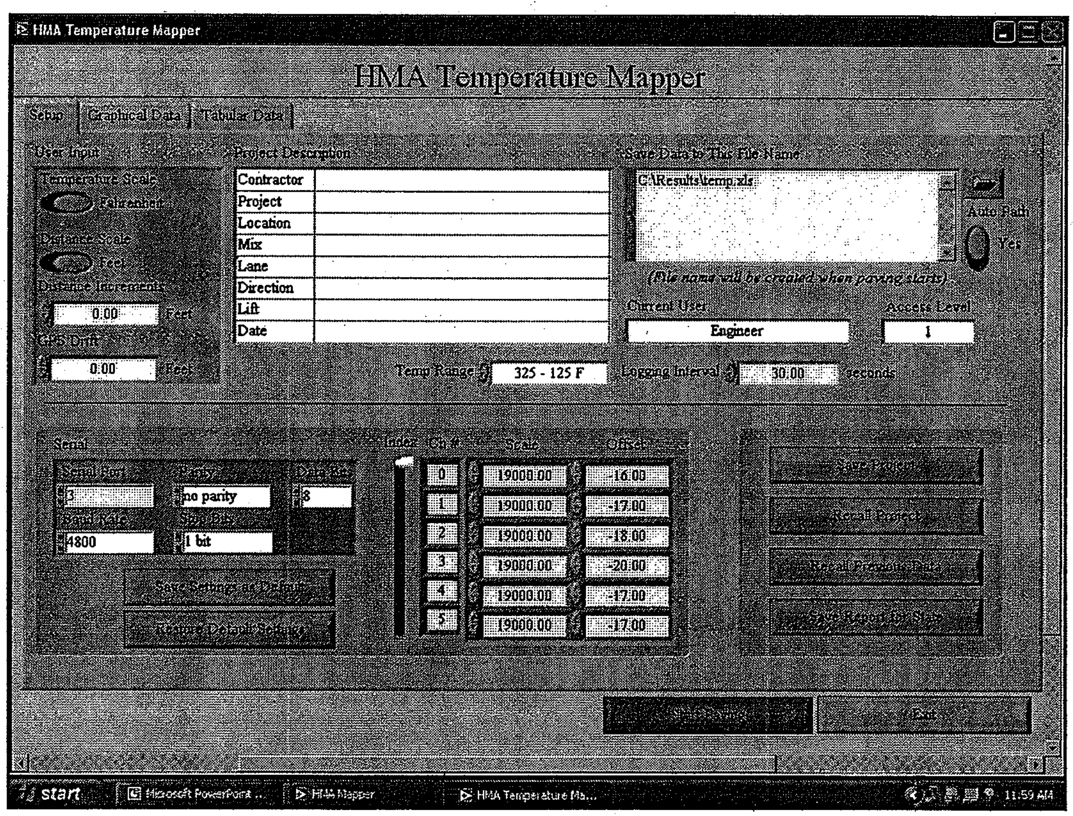



**Figure 3. Setup screen**

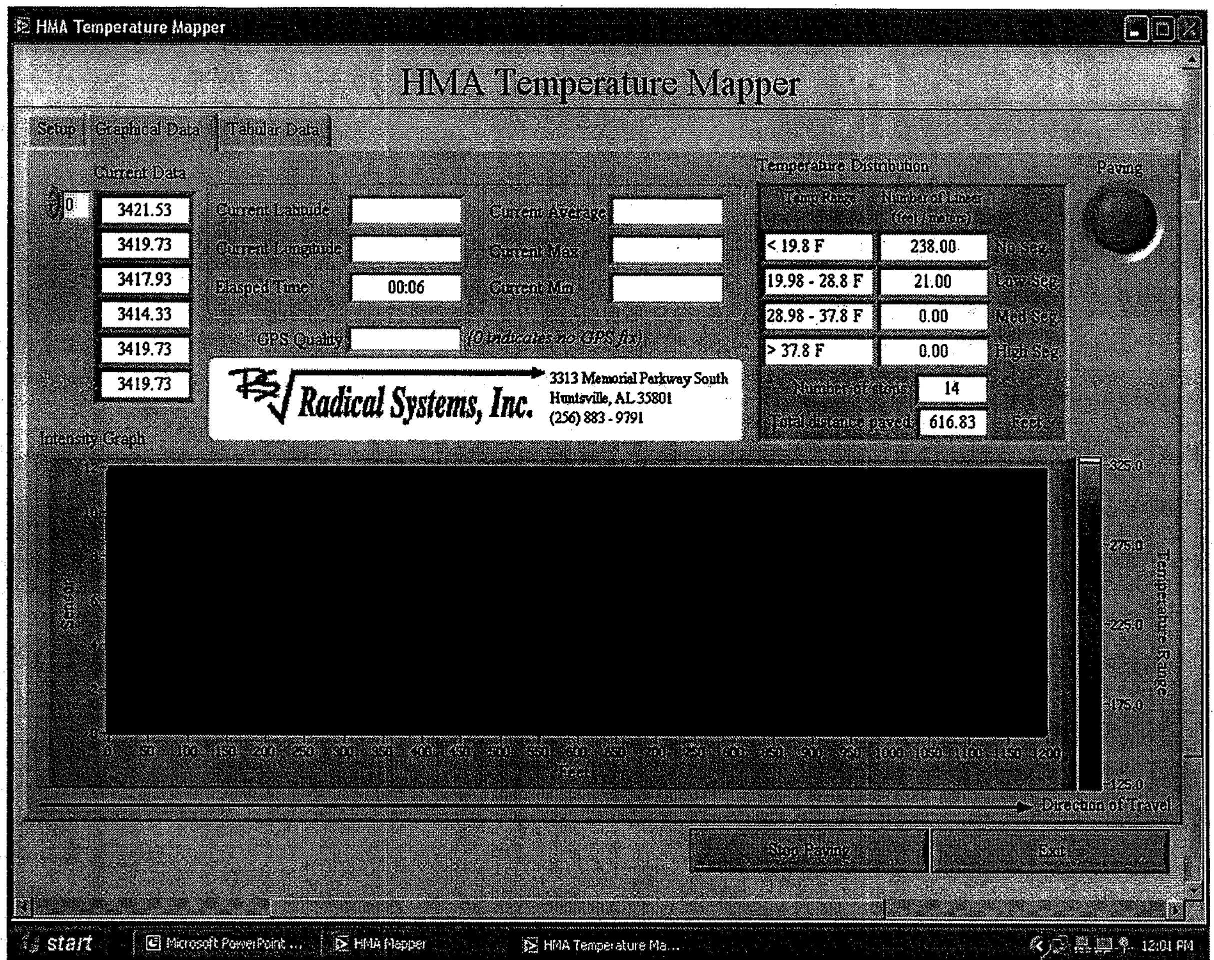
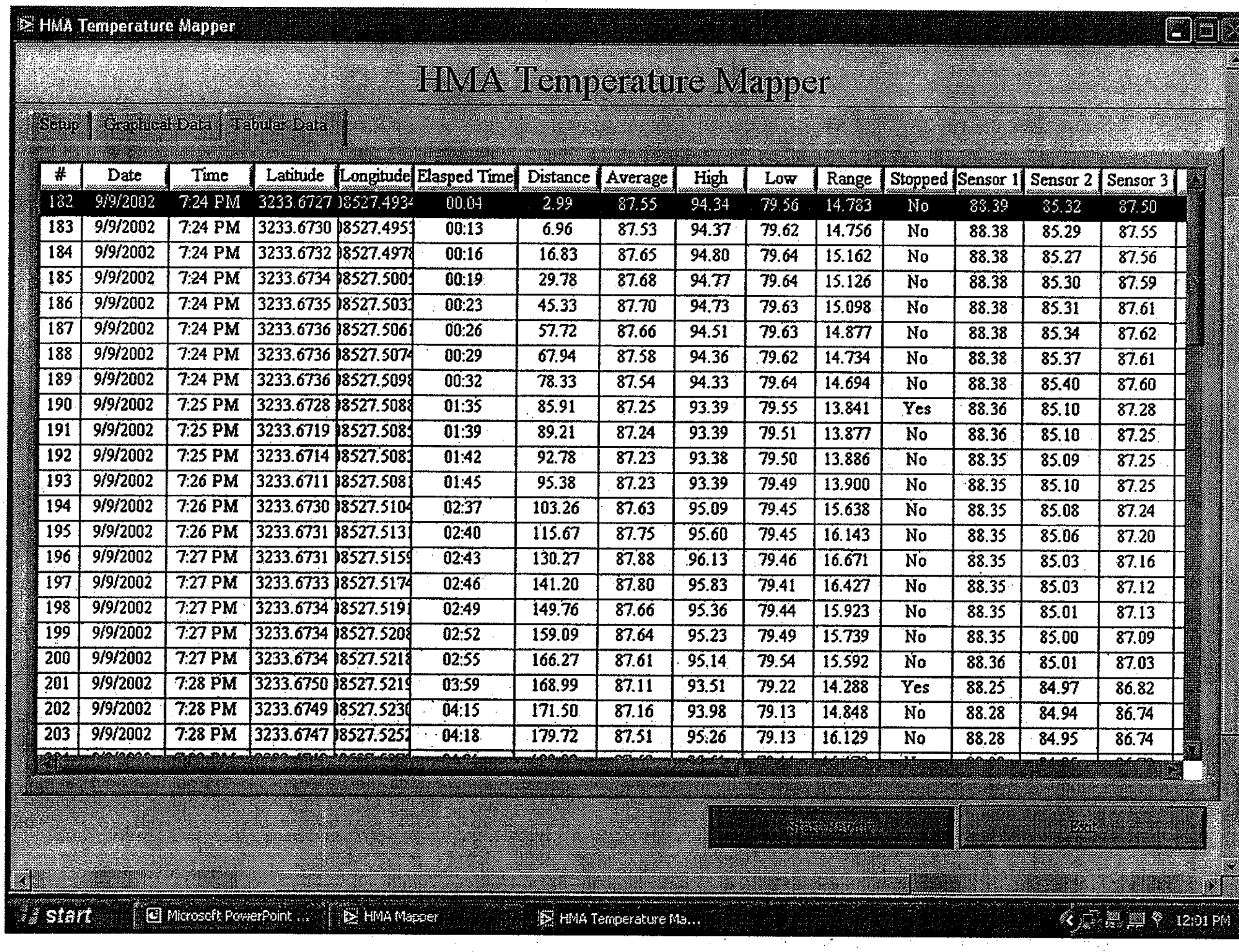



**Figure 4. Graphical data screen**




| # | Date | Time | Latitude | Longitude | Elasped Time | Distance | Average | High | Low | Range | Stopped | Sensor 1 | Sensor 2 | Sensor 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 182 | 9/9/2002 | 7:24 PM | 3233.6727 | 8527.4934 | 00:04 | 2.99 | 87.55 | 94.34 | 79.56 | 14.783 | No | 88.39 | 85.32 | 87.50 |
| 183 | 9/9/2002 | 7:24 PM | 3233.6730 | 8527.495 | 00:13 | 6.96 | 87.53 | 94.37 | 79.62 | 14.756 | No | 88.38 | 85.29 | 87.55 |
| 184 | 9/9/2002 | 7:24 PM | 3233.6732 | 8527.4978 | 00:16 | 16.83 | 87.65 | 94.80 | 79.64 | 15.162 | No | 88.38 | 85.27 | 87.56 |
| 185 | 9/9/2002 | 7:24 PM | 3233.6734 | 8527.500 | 00:19 | 29.78 | 87.68 | 94.77 | 79.64 | 15.126 | No | 88.38 | 85.30 | 87.59 |
| 186 | 9/9/2002 | 7:24 PM | 3233.6735 | 8527.503 | 00:23 | 45.33 | 87.70 | 94.73 | 79.63 | 15.098 | No | 88.38 | 85.31 | 87.61 |
| 187 | 9/9/2002 | 7:24 PM | 3233.6736 | 8527.506 | 00:26 | 57.72 | 87.66 | 94.51 | 79.63 | 14.877 | No | 88.38 | 85.34 | 87.62 |
| 188 | 9/9/2002 | 7:24 PM | 3233.6736 | 8527.5074 | 00:29 | 67.94 | 87.58 | 94.36 | 79.62 | 14.734 | No | 88.38 | 85.37 | 87.61 |
| 189 | 9/9/2002 | 7:24 PM | 3233.6736 | 8527.5098 | 00:32 | 78.33 | 87.54 | 94.33 | 79.64 | 14.694 | No | 88.38 | 85.40 | 87.60 |
| 190 | 9/9/2002 | 7:25 PM | 3233.6728 | 8527.5088 | 01:35 | 85.91 | 87.25 | 93.39 | 79.55 | 13.841 | Yes | 88.36 | 85.10 | 87.28 |
| 191 | 9/9/2002 | 7:25 PM | 3233.6719 | 8527.508 | 01:39 | 89.21 | 87.24 | 93.39 | 79.51 | 13.877 | No | 88.36 | 85.10 | 87.25 |
| 192 | 9/9/2002 | 7:25 PM | 3233.6714 | 8527.508 | 01:42 | 92.78 | 87.23 | 93.38 | 79.50 | 13.886 | No | 88.35 | 85.09 | 87.25 |
| 193 | 9/9/2002 | 7:26 PM | 3233.6711 | 8527.508 | 01:45 | 95.38 | 87.23 | 93.39 | 79.49 | 13.900 | No | 88.35 | 85.10 | 87.25 |
| 194 | 9/9/2002 | 7:26 PM | 3233.6730 | 8527.5104 | 02:37 | 103.26 | 87.63 | 95.09 | 79.45 | 15.638 | No | 88.35 | 85.08 | 87.24 |
| 195 | 9/9/2002 | 7:26 PM | 3233.6731 | 8527.513 | 02:40 | 115.67 | 87.75 | 95.60 | 79.45 | 16.143 | No | 88.35 | 85.06 | 87.20 |
| 196 | 9/9/2002 | 7:27 PM | 3233.6731 | 8527.515 | 02:43 | 130.27 | 87.88 | 96.13 | 79.46 | 16.671 | No | 88.35 | 85.03 | 87.16 |
| 197 | 9/9/2002 | 7:27 PM | 3233.6733 | 8527.5174 | 02:46 | 141.20 | 87.80 | 95.83 | 79.41 | 16.427 | No | 88.35 | 85.03 | 87.12 |
| 198 | 9/9/2002 | 7:27 PM | 3233.6734 | 8527.519 | 02:49 | 149.76 | 87.66 | 95.36 | 79.44 | 15.923 | No | 88.35 | 85.01 | 87.13 |
| 199 | 9/9/2002 | 7:27 PM | 3233.6734 | 8527.5208 | 02:52 | 159.09 | 87.64 | 95.23 | 79.49 | 15.739 | No | 88.35 | 85.00 | 87.09 |
| 200 | 9/9/2002 | 7:27 PM | 3233.6734 | 8527.5218 | 02:55 | 166.27 | 87.61 | 95.14 | 79.54 | 15.592 | No | 88.36 | 85.01 | 87.03 |
| 201 | 9/9/2002 | 7:28 PM | 3233.6750 | 8527.521 | 03:59 | 168.99 | 87.11 | 93.51 | 79.22 | 14.288 | Yes | 88.25 | 84.97 | 86.82 |
| 202 | 9/9/2002 | 7:28 PM | 3233.6749 | 8527.523 | 04:15 | 171.50 | 87.16 | 93.98 | 79.13 | 14.848 | No | 88.28 | 84.94 | 86.74 |
| 203 | 9/9/2002 | 7:28 PM | 3233.6747 | 8527.525 | 04:18 | 179.72 | 87.51 | 95.26 | 79.13 | 16.129 | No | 88.28 | 84.95 | 86.74 |

**Figure 5. Tabular data screen**

## Fitting the Sensor Bar to the Paver

Figure 6 shows the first attempt at attaching the sensor bar to the paver. Both the horizontal sensor bars and the vertical risers are substantially oversized because of the flexibility needed in repositioning both the sensors and the height of the bars. It is anticipated that the size of the members can be substantially reduced once these parameters are fixed.

An evaluation by the contractor identified the following problems with the initial design:

- The bar was too close to the walkway. This would be a problem with the person adjusting the screed and taking lift thickness checks from the back of the paver.
- The closeness of the bar may also pose a safety problem in case of emergency. Occasionally, problems arise, either from paver problems or traffic problems, that require a rapid exit off of the paver by both the paver operator located in one of the seats on the upper deck and the screed operator.
- The clamps and the flat plates might be a tripping hazard as people move back and forth on the walkway.
- The vertical risers need to be placed at third point locations on the transverse bar (Figure 7).

Based on these comments, the bars and attachments were altered so that the bar is cantilevered away from the walkway (Figure 7). The contractor tentatively approved this attachment for a trial run on a project away from high traffic volumes.

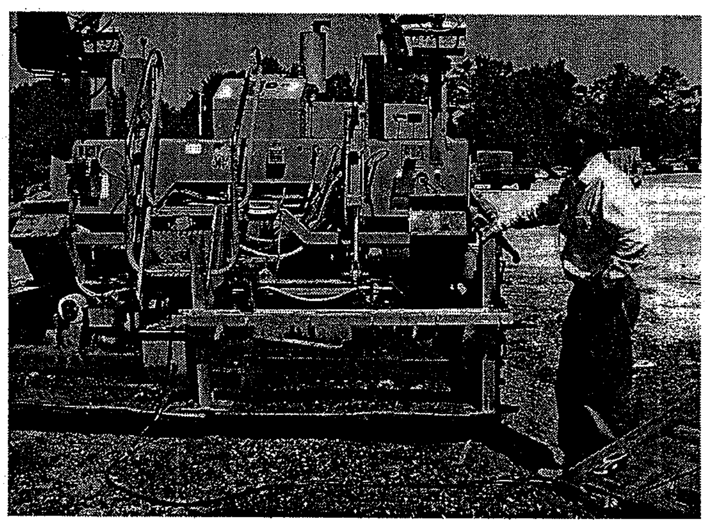


**Figure 6. First attempt at mounting sensor bar**

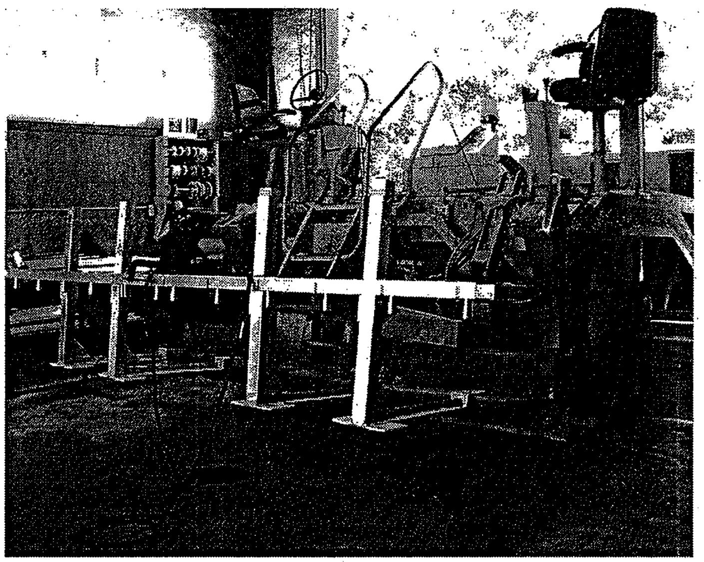


**Figure 7. Second attempt at mounting sensor bar**

## Operating the Electronics

Power is supplied to the computer and the aquarium pump by using an inverter to convert the power from a 12 amp-hour 12 volt battery into 110 volts. The inverter has plugs for up to three grounded plugs. Figure 8 shows the power consumption by an older computer with the screen constantly on and the aquarium pump. This figure shows that at maximum power requirements, the system can run for about 2.5 hours. A significant increase in the length of time is obtained by upgrading the computer to a newer version that uses a transformer to reduce the power requirements.

The battery, inverter, two signal conditioners, and portable computer are mounted on a small tray clamped to the top of one of the transverse sensor bar. This location allows for the monitoring and adjustment by the researchers on the ground near the sensor bar. This also allows the researchers to stay out of the way of the workers repairing any areas on the mat during the paving operations.

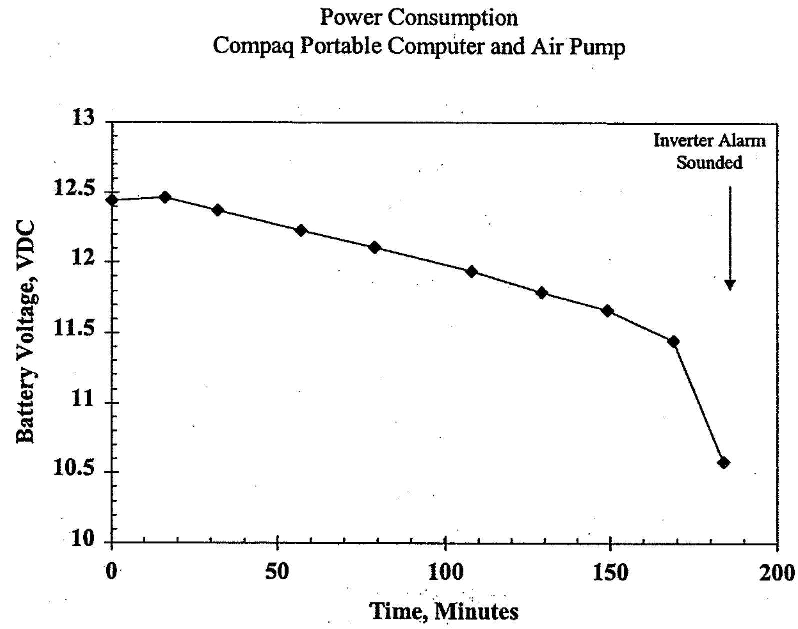



**Figure 8. Power consumption using old portable computer and aquarium pump**

## RESULTS AND DISCUSSION

### Preliminary Calibration

Once the system was assembled, the scale and offset values for each of the sensors were determined using heat sources with temperatures within the linear range of the sensors [between 145 to 175°C (290 to 350°F)]. The software allows these parameters to be stored as default values that can be recalled as needed. The scale, which keeps the range of temperatures consistent over the linear range, was consistent between all of the sensors. Minor adjustments were needed for the offset values that essentially sets the readings to a known reading (i.e., the null point).

## GPS Evaluation

Parameters to stabilize the information obtained from the GPS antennae can be entered on the setup screen. The two parameters that need to be adjusted are the distance increment and the GPS drift. The distance setting seems to stabilize the readings so that the values do not jump around. The drift tends to set the accuracy of the distance readings.

In order to determine the best settings for the GPS parameter, the entire system was mounted on the back of a pickup (Figure 9). A 165 meter (550 foot) lap around an existing pavement was marked off with a manual distance measurement wheel. This track was then used for the initial evaluation of both the GPS system and the infrared sensors. Figure 10 shows the relationship between the distance traveled as reported by the GPS through the HMA Temperature Mapping program and that measured manually. The ratios shown in this figure indicate the values used for the distance (in feet) and GPS drift settings, respectively. Based on these results, values of 3 feet for the distance increment and 1 for the GPS drift were selected as the default settings.


**Figure 9. Setup on the back of the pickup for calibration of GPS and infrared sensors**

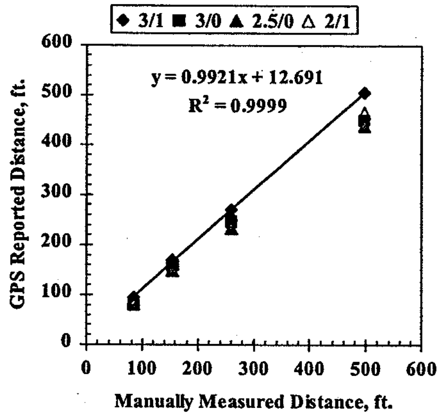



**Figure 10. Comparison of measured and GPS-reported distances**

## Trial Runs of Existing Pavement

The setup shown in Figure 9 was used to evaluate the sensors ability to measure temperature at two different heights above a black surface. One of the 6-sensor bars was set up so that sensors were 45.7 cm (18 inches) above the bed of the truck that was fitted with a black bed liner. An existing roadway of approximately 61meters (200 feet) with a uniform color and exposure to full August sun was selected for evaluating the 6-sensor bar suspended 122 cm (48 inches) above the pavement. The black bed liner had a temperature, as measured with a hand held infrared gun of 50°C (122°F). The average pavement temperature was 49C (120°F). The average reading from the sensor bars was about 91°F (33°C) at the beginning of the test section. This is about 19°F lower than the values obtained using the hand held infrared gun. However, this temperature is also about 100°F below the lower limit for linear sensor response. Therefore, the default settings, selected for accuracy within the linear range were not changed. The assumption was that since the objective of the sensor bar is to determine the temperature differential across the back of the paver, that these results could be used to determine if this system could accomplish this task.

This set up was used to evaluate the effect of the vehicle speed on the infrared measurements. Figure 11 shows the results of two vehicle speeds. The program was set to collect data every three seconds so the numbers of data points in each line can be used as an indication of vehicle speed. The first run at 3:51 pm shows an initial dip in the pavement temperature followed by a steadily increasing temperature over the length of the roadway. The overlapping data points for this run indicate a very slow vehicle speed. The second run shown in this figure indicates good agreement between the two runs up to about 125 feet (38.1 meters). When the vehicle speed was noticeably increased, the temperature readings between the two runs begin to deviate substantially. Since paving speeds are closer to those used for the first run, the repeatability of the measurements at slow speeds was considered adequate.

A second test section of 165 meters (550 feet) long was marked off with a manual distance measurement wheel. Intermediate distances of 26, 47, 79, and 151 meters (85, 155, 260, and 496 feet) were also marked and used as point at which to stop the truck. Figure 12 shows the results from four runs. This section had random areas of full sun and shade so that a range of pavement temperatures was obtained. The temperature in the bed of the truck changed as the truck moved through areas of full sun and full shade (Figure 12). The temperature of the pavement remained relatively constant over the short testing time, regardless of the increasing shade on the pavement surface. This is due to the mass of the pavement structure and its slow loss of heat as compared to the thin bed liner. Hand held infrared measurements of the temperature in the bed of the truck were 49C (120°F) and 38°C (101°F) on the pavement under the sensor bar at a distance of 26 meters (85 feet). Figure 12 shows that while the sensor distances above the surface being measured ranged from 46 cm (18 inches) in the bed of the truck to 122 cm (48 inches) above the pavement surface, the difference between the hand held infrared gun temperature and the sensor bar temperature was consistently about 11°C (20°F). This indicates that the sensor readings are not sensitive to the distance above a surface with a relatively uniform temperature.

Figure 13 shows four different runs at varying times as the sun was setting. As both the pavement surface cool (very slowly) and the black bed liner cools (rapidly), the temperatures both cool with time and become more repeatable. The consistency of the various temperature characteristics shown by each of the runs also provides confirmation that the GPS system is accurately reporting the distance traveled.

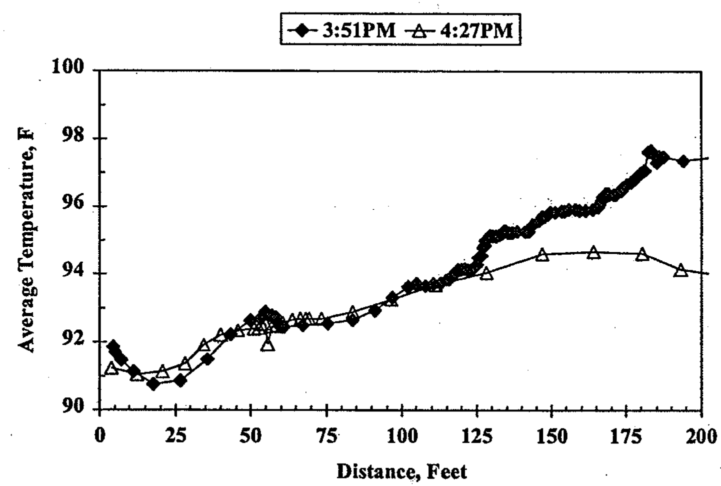



**Figure 11. Average reported infrared sensor bar temperature for two runs (different vehicle speeds)**

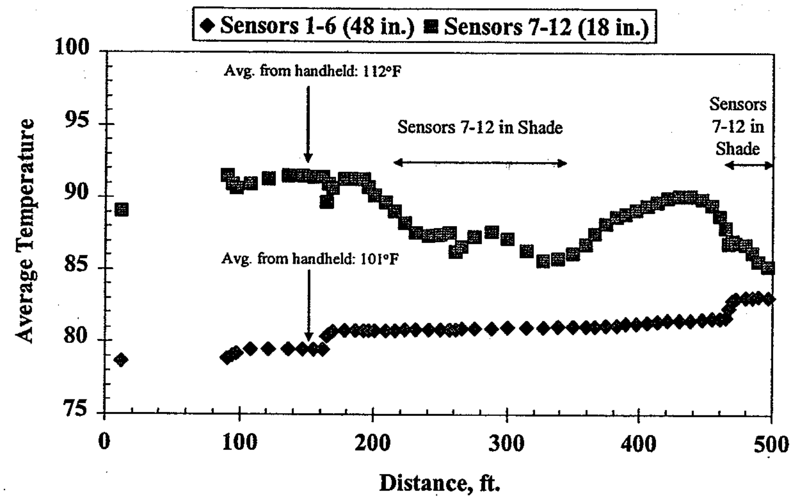



**Figure 12. Differences in average sensor bar temperatures depending on position on truck**

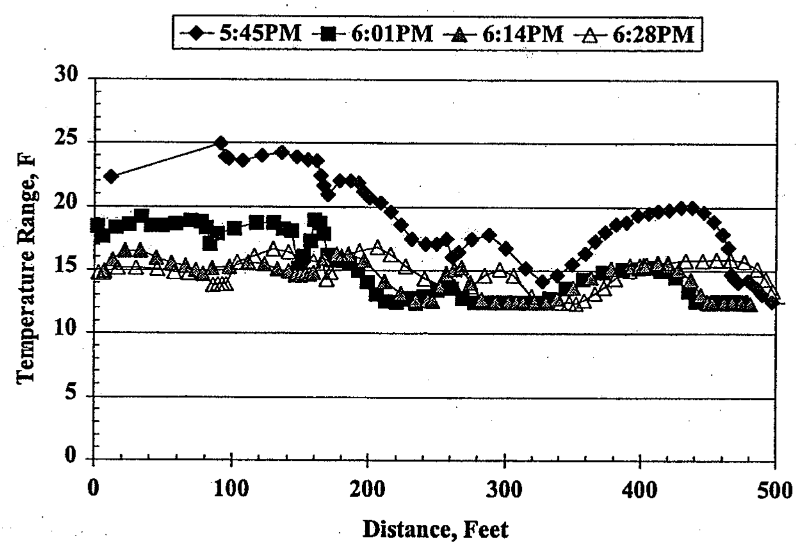



**Figure 13. Average temperature for four consecutive runs**

The software is also designed to record if measurable temperature differentials are the result of a paver stop. This software feature was also evaluated during these initial runs. The truck was stopped at each of the intermediate distances noted above for at least one minute. The software accurately counted each stop (software set to indicate stop of more than 1 minute).

### Software Reports

The project data is saved on the setup screen (Figure 3). Once saved, it can be used to generate a report for an agency that reports the location of any areas that have temperatures that indicate the possibility of segregation. The agency report, saved as an htm file, can be opened and printed from Microsoft word (Appendix A). The number of times that the paver stops for more than 1 minute are also recorded, however the locations are not recorded unless there is also a temperature differential. This problem needs to be addressed in any future software changes. The data is grouped by the level of segregation (i.e., range of transverse temperatures) and includes both the latitude and longitude from the GPS system for location these areas at a later time.

The entire data set is also saved in a *.dat file for further analysis in any spreadsheet program.

## CONCLUSIONS

The following conclusions can be drawn from this research:

- The initial development of a prototype infrared sensor bar was successfully used to evaluate pavement temperature differentials.
- The infrared sensor measurements seem to be insensitive to the height above the surface as long as the surface has a relatively uniform temperature.
- Measurements can be sensitive to the vehicle speed. However, since the speed of a paving operation is very slow, this should not be a problem.

- The GPS system seems to be reasonably accurate for determining the distance traveled. This implies that any construction anomalies can be located with a hand held GPS unit using the latitude and longitude recorded by the software.
- The software works well for presenting data to the operator during paving as well as recording non-uniform areas found during paving.
- The power requirements of the electronics can limit the time over which data can be collected. This system as designed would be best placed on a newer paver with power access.
- The cables that connect the sensors to the computer and the airlines that connect to the pump are awkward to work with and cumbersome to handle during the set up of the equipment on the paver.

## RECOMMENDATIONS

Due to time constraints, software development difficulties, and problems with getting the GPS system data acquisition to stabilize, an actual paving project could not be evaluated by the time this final report was due.

Discussions with various contractors during the development of the prototype led to the suggestion that the sensor bar could easily be suspended from over the top of the paver rather than mounted to the back of the screed. This would eliminate any problems with the bar interfering with the movement of the personnel on and around the paver. Since this would place the sensors about 2.5 meters (8 feet) above the surface, the affect of height on the sensor readings will need to be addressed again if this configuration is adapted.

The software should be adjusted so that it logs the location of stops in the agency report file whether or not there is a significant transverse temperature differential across the back of the paver. At this time, the program only counts the stops but does not record the location unless the temperature differential meets one of the levels of segregation definitions.

An infrared sensor upgrade is recommended. After this project was under way, a new type of infrared sensor marketed by TransTec, with a built-in fan in place of the air purge came on the market. This sensor also has remote access capabilities for data collection. This combination of features would eliminate both the electronic cabling and airlines. The data collection system could be placed well away from the paving operation if these sensors are used.

## BIBLIOGRAPHY

Stroup-Gardiner, M., and Brown, E.R. *Segregation in Hot-Mix Asphalt Pavements*. National Cooperative Highway Research Program Report 411. National Academy Press, Washington, D.C., 2000.

## APPENDIX A

## Example of Agency Report

**Final Report for State Agency**

| | |
|---|---|
| Contractor | Gardiner |
| Project | Truck run for evaluating sensor height and GPS |
| Location | Driveway |
| Mix | Old, dense HMA |
| Lane | 1 lane |
| Direction | Clockwise |
| Lift | Top |
| Date | 9-09-02 |

**SUMMARY**

**Total Number of Paver Stops: 14**

Percent Low Segregation 91 (number of increments with low segregation/total number of increments)

Percent Med Segregation 9 (number of increments with med segregation/total number of increments)

Percent High Segregation 0 (number of increments with high segregation/total number of increments)

**LOCATION OF INDIVIDUAL NON-UNIFORMITIES**

Low Segregation:

Temp Range 11.1 - 16.0C (19.98 - 28.8F)

| Latitude | Longitude | Distance Traveled | Max Temp | Min Temp | Mean Temp | Stop? |
|---|---|---|---|---|---|---|
| 3233.6727 | 08527.4934 | 2.99 | 94.34 | 79.56 | 87.55 | No |
| 3233.6730 | 08527.4953 | 6.96 | 94.37 | 79.62 | 87.53 | No |
| 3233.6732 | 08527.4978 | 16.83 | 94.80 | 79.64 | 87.65 | No |
| 3233.6734 | 08527.5005 | 29.78 | 94.77 | 79.64 | 87.68 | No |
| 3233.6735 | 08527.5033 | 45.33 | 94.73 | 79.63 | 87.70 | No |
| 3233.6736 | 08527.5061 | 57.72 | 94.51 | 79.63 | 87.66 | No |
| 3233.6736 | 08527.5074 | 67.94 | 94.36 | 79.62 | 87.58 | No |
| 3233.6736 | 08527.5098 | 78.33 | 94.33 | 79.64 | 87.54 | No |
| 3233.6728 | 08527.5088 | 85.91 | 93.39 | 79.55 | 87.25 | No |
| 3233.6719 | 08527.5085 | 89.21 | 93.39 | 79.51 | 87.24 | No |
| 3233.6714 | 08527.5083 | 92.78 | 93.38 | 79.50 | 87.23 | No |
| 3233.6711 | 08527.5081 | 95.38 | 93.39 | 79.49 | 87.23 | No |
| 3233.6730 | 08527.5104 | 103.26 | 95.09 | 79.45 | 87.63 | No |
| 3233.6734 | 08527.5191 | 149.76 | 95.36 | 79.44 | 87.66 | No |
| 3233.6734 | 08527.5208 | 159.09 | 95.23 | 79.49 | 87.64 | No |
| 3233.6734 | 08527.5218 | 166.27 | 95.14 | 79.54 | 87.61 | No |
| 3233.6750 | 08527.5219 | 168.99 | 93.51 | 79.22 | 87.11 | No |
| 3233.6749 | 08527.5230 | 171.50 | 93.98 | 79.13 | 87.16 | No |
| 3233.6718 | 08527.5334 | 226.59 | 94.47 | 79.14 | 87.24 | No |
| 3233.6701 | 08527.5352 | 241.00 | 93.58 | 79.17 | 86.93 | No |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3233.6681 | 08527.5366 | 253.30 | 93.06 | 79.21 | 86.75 | No |
| 3233.6669 | 08527.5370 | 263.01 | 93.00 | 79.19 | 86.67 | No |
| 3233.6664 | 08527.5375 | 269.76 | 91.90 | 78.93 | 86.13 | No |
| 3233.6642 | 08527.5379 | 274.98 | 92.61 | 78.91 | 86.29 | No |
| 3233.6625 | 08527.5382 | 284.98 | 93.45 | 78.87 | 86.52 | No |
| 3233.6608 | 08527.5385 | 295.68 | 93.94 | 78.88 | 86.68 | No |
| 3233.6589 | 08527.5388 | 306.33 | 93.51 | 78.91 | 86.62 | No |
| 3233.6570 | 08527.5392 | 319.22 | 91.85 | 78.92 | 86.23 | No |
| 3233.6551 | 08527.5391 | 330.51 | 91.44 | 78.94 | 86.05 | No |
| 3233.6539 | 08527.5389 | 340.77 | 91.42 | 78.93 | 85.95 | No |
| 3233.6532 | 08527.5384 | 347.34 | 91.40 | 78.94 | 86.02 | No |
| 3233.6525 | 08527.5378 | 352.15 | 91.36 | 78.93 | 86.04 | No |
| 3233.6518 | 08527.5367 | 358.54 | 91.56 | 78.94 | 86.16 | No |
| 3233.6514 | 08527.5354 | 366.40 | 92.10 | 78.95 | 86.28 | No |
| 3233.6512 | 08527.5342 | 372.90 | 92.60 | 78.97 | 86.43 | No |
| 3233.6508 | 08527.5323 | 380.88 | 93.37 | 78.98 | 86.66 | No |
| 3233.6504 | 08527.5302 | 392.42 | 93.95 | 78.98 | 86.89 | No |
| 3233.6500 | 08527.5282 | 402.57 | 94.43 | 78.97 | 87.03 | No |
| 3233.6496 | 08527.5259 | 412.61 | 94.61 | 78.96 | 87.04 | No |
| 3233.6494 | 08527.5245 | 420.24 | 94.63 | 78.97 | 87.02 | No |
| 3233.6486 | 08527.5215 | 433.39 | 94.71 | 78.95 | 87.03 | No |
| 3233.6482 | 08527.5196 | 445.99 | 94.73 | 78.93 | 87.08 | No |
| 3233.6477 | 08527.5180 | 455.70 | 94.80 | 78.92 | 87.15 | No |
| 3233.6472 | 08527.5159 | 466.14 | 94.75 | 78.92 | 87.14 | No |
| 3233.6468 | 08527.5142 | 476.22 | 94.60 | 78.93 | 87.14 | No |
| 3233.6466 | 08527.5126 | 485.80 | 94.11 | 78.92 | 87.01 | No |
| 3233.6464 | 08527.5116 | 492.91 | 93.30 | 78.92 | 86.77 | No |
| 3233.6462 | 08527.5108 | 497.59 | 92.34 | 78.93 | 86.48 | No |
| 3233.6461 | 08527.5100 | 502.09 | 91.40 | 78.89 | 86.16 | No |
| 3233.6461 | 08527.5098 | 504.70 | 91.36 | 78.90 | 85.91 | No |
| 3233.6446 | 08527.5097 | 510.62 | 91.28 | 78.76 | 85.41 | No |
| 3233.6443 | 08527.5097 | 516.90 | 91.30 | 78.80 | 85.40 | No |
| 3233.6436 | 08527.5101 | 519.54 | 91.32 | 78.81 | 85.39 | No |
| 3233.6425 | 08527.5107 | 524.93 | 91.30 | 78.82 | 85.37 | No |
| 3233.6417 | 08527.5112 | 531.84 | 91.34 | 78.77 | 85.36 | No |
| 3233.6410 | 08527.5116 | 537.21 | 91.23 | 78.72 | 85.33 | No |
| 3233.6408 | 08527.5120 | 540.91 | 91.25 | 78.72 | 85.31 | No |
| 3233.6404 | 08527.5119 | 543.83 | 91.12 | 78.60 | 85.19 | No |
| 3233.6425 | 08527.5115 | 546.48 | 90.98 | 78.45 | 85.09 | No |
| 3233.6432 | 08527.5117 | 549.16 | 90.87 | 78.36 | 85.10 | No |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3233.6415 | 08527.5121 | 555.12 | 90.84 | 78.26 | 85.03 | No |
| 3233.6412 | 08527.5118 | 558.84 | 90.85 | 78.26 | 85.01 | No |
| 3233.6418 | 08527.5111 | 561.89 | 90.82 | 78.23 | 85.01 | No |
| 3233.6423 | 08527.5106 | 566.70 | 90.83 | 78.25 | 85.00 | No |
| 3233.6430 | 08527.5102 | 571.18 | 90.82 | 78.25 | 84.98 | No |
| 3233.6437 | 08527.5099 | 575.90 | 90.81 | 78.28 | 84.95 | No |
| 3233.6423 | 08527.5101 | 580.55 | 90.75 | 78.24 | 84.89 | No |
| 3233.6429 | 08527.5063 | 590.04 | 90.74 | 78.16 | 84.94 | No |
| 3233.6424 | 08527.5042 | 602.24 | 90.69 | 78.14 | 84.81 | No |
| 3233.6421 | 08527.5026 | 612.77 | 90.71 | 78.14 | 84.78 | No |
| 3233.6422 | 08527.5027 | 616.83 | 90.72 | 78.16 | 84.69 | No |

Med Segregation:

Temp Range 16.1 - 21.0C (28.98 - 37.8F)

| Latitude | Longitude | Distance Traveled | Max Temp | Min Temp | Mean Temp | Stop? |
|---|---|---|---|---|---|---|
| 3233.6731 | 08527.5131 | 115.67 | 95.60 | 79.45 | 87.75 | No |
| 3233.6731 | 08527.5159 | 130.27 | 96.13 | 79.46 | 87.88 | No |
| 3233.6733 | 08527.5174 | 141.20 | 95.83 | 79.41 | 87.80 | No |
| 3233.6747 | 08527.5252 | 179.72 | 95.26 | 79.13 | 87.51 | No |
| 3233.6742 | 08527.5278 | 192.98 | 95.61 | 79.14 | 87.63 | No |
| 3233.6736 | 08527.5298 | 206.03 | 95.93 | 79.12 | 87.73 | No |
| 3233.6730 | 08527.5315 | 215.97 | 95.40 | 79.12 | 87.57 | No |

High Segregation:

Temp Range > 21C (37.8F)

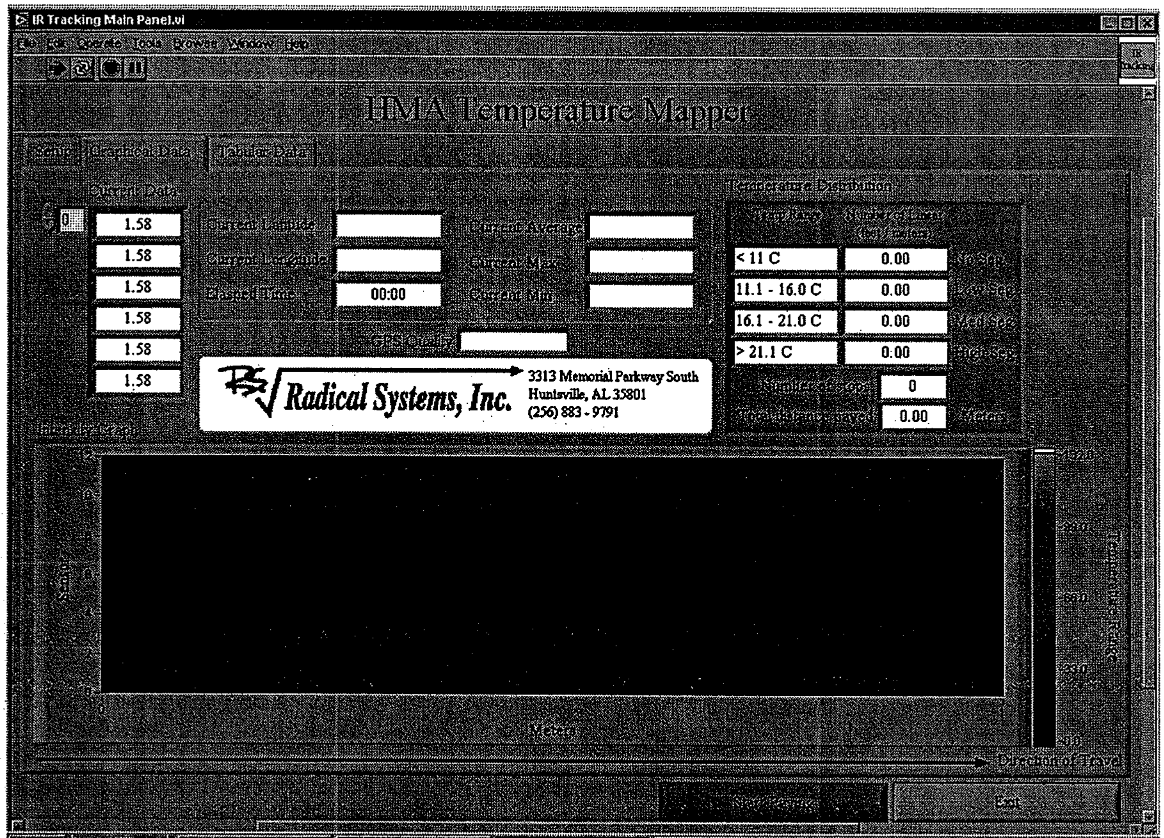
| Latitude | Longitude | Distance Traveled | Max Temp | Min Temp | Mean Temp | Stop? |
|---|---|---|---|---|---|---|

## APPENDIX B

## INSTRUCITON MANUAL FOR THE HMA TEMPERATURE MAPPER PROGRAM

HMA Temperature Mapper

The HMA Temperature is a LabVIEW based data collection system that measures 12 temperature sensors and uses GPS data to measure position and movement. Using National Instruments hardware and a Garmin GPS the software collects data, stores results in a spreadsheet format, and generates reports for the state agency. Operation is intuitive using on screen buttons and controls.

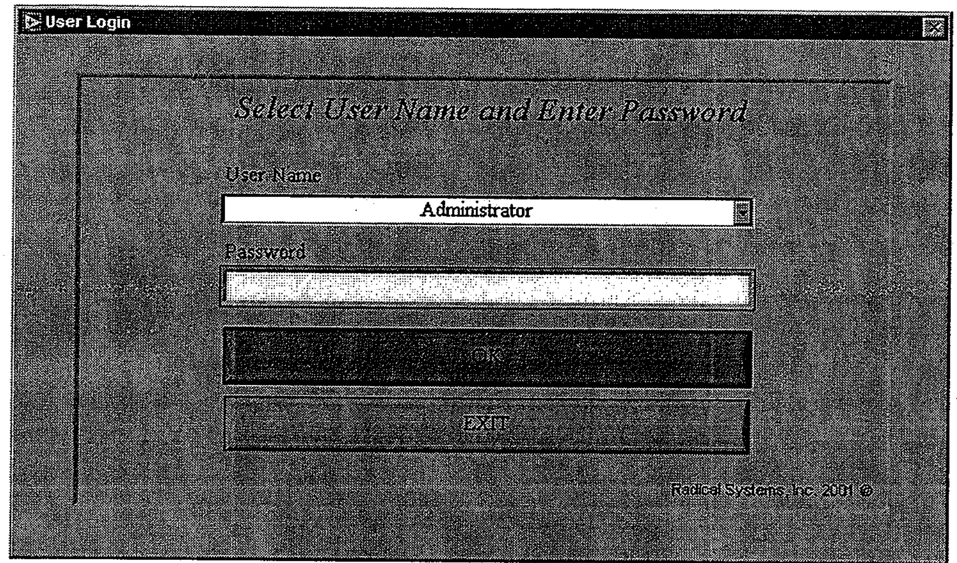


HMA Temperature Mapper Graphical Data Panel

## Logging In

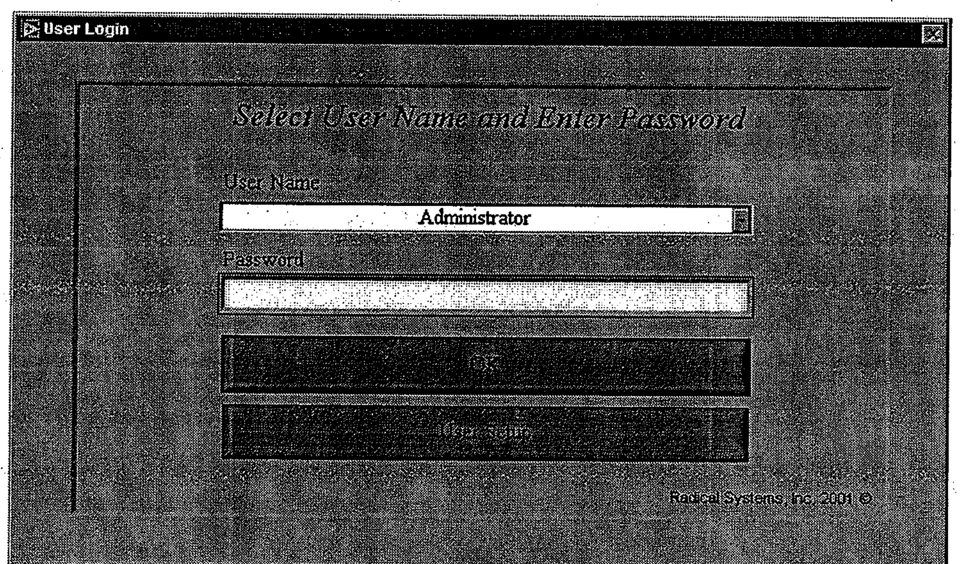
The system is protected from unauthorized use by requiring operators to log in with a password. Operators select their name from a pick list, entering their password in the space provided and then pressing 'Return' or clicking on the 'OK' button. Depending on user access level the system will behave in 1 of 2 ways.

1. If the user logged in only has user access permissions the login panel will close and user will be ready to use the system.
2. If the user logs in with a higher access level the login panel will remain open and the 'EXIT' button at the bottom changes to 'User Setup'

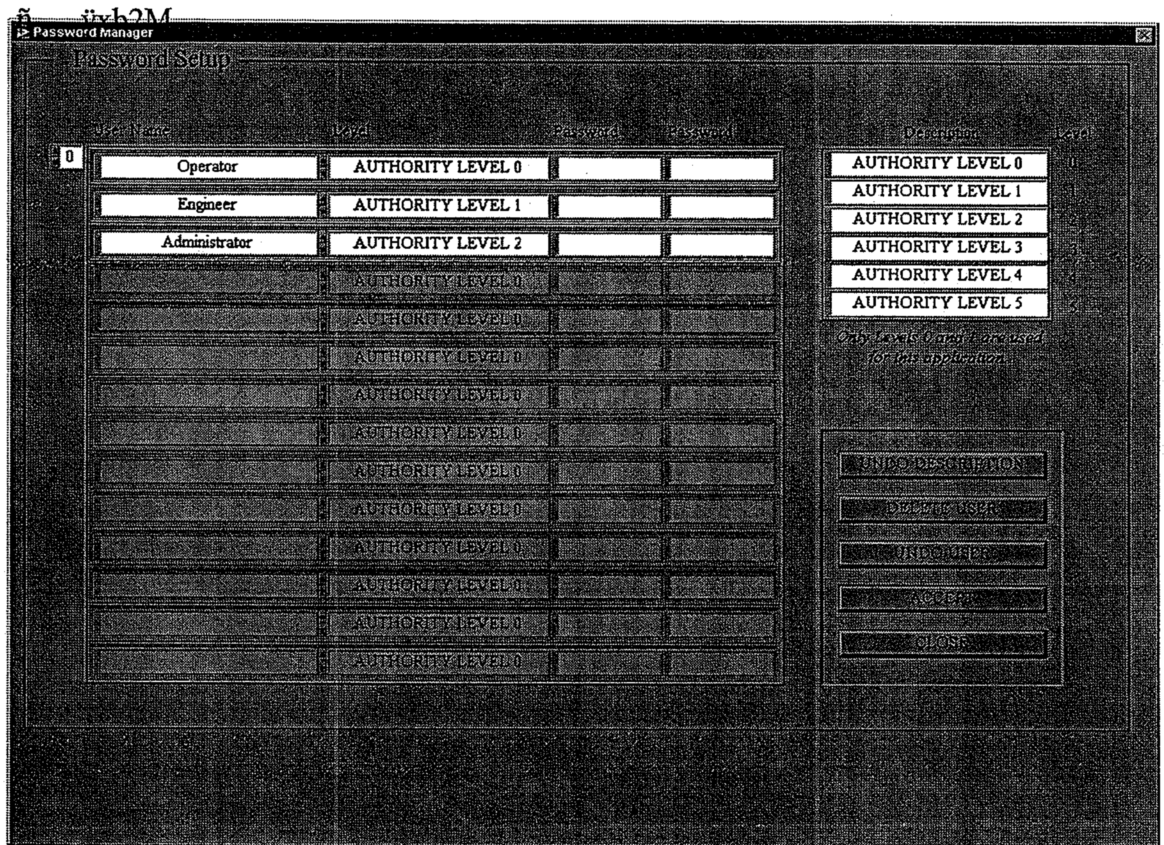



Password Panel

To exit the system without logging in, press the 'EXIT' button.



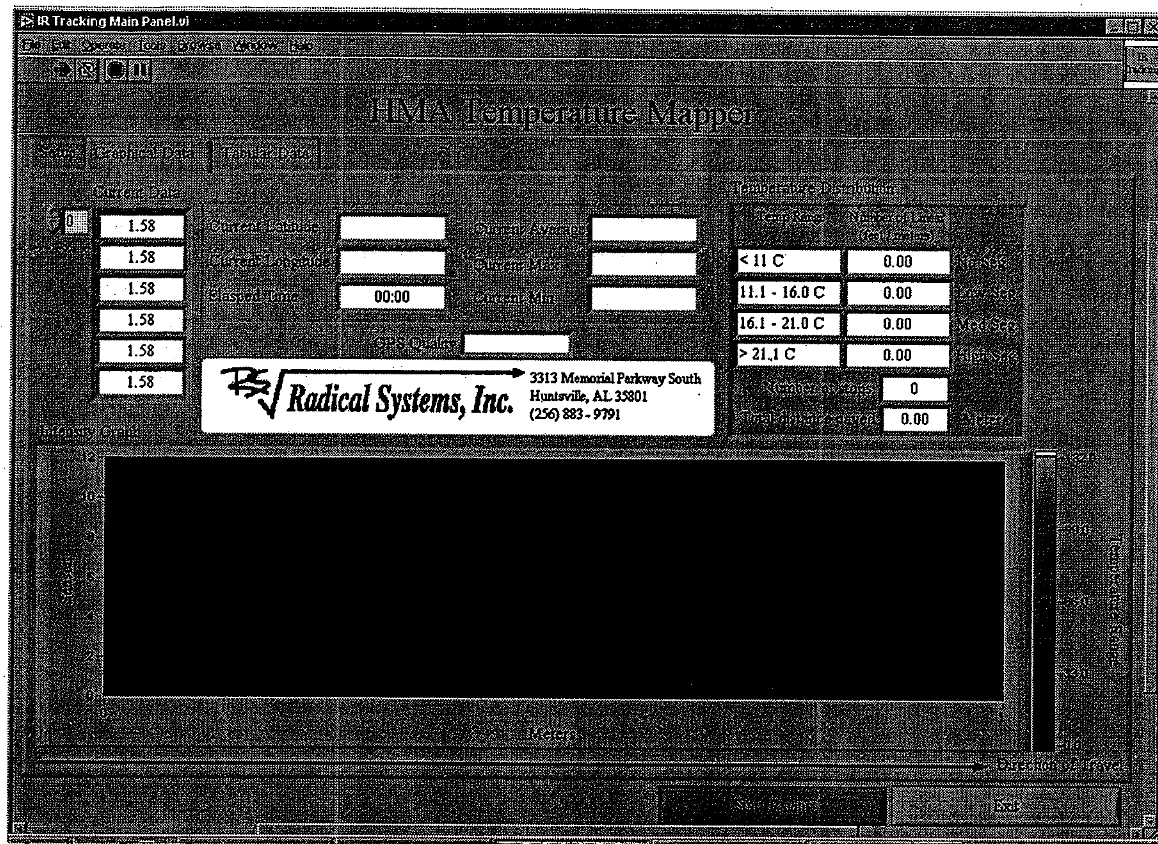

Password Panel Showing 'User Setup' Button




Password and User Management Panel

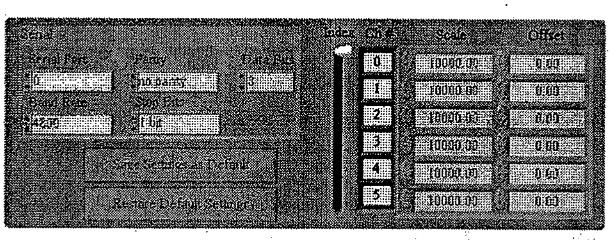
- To add a new user – type the name in the list under the 'User Name' column. Select the authority level from the list provided. Only levels 0 and 1 are used for the system. Enter the desired password in each of the 'Password' blanks.
- To delete a user – use the index control at the top left of the to move the user to be deleted to the top of the page. Press the 'Delete User' button on the right; the user at the top of the list will be removed. Use the index control to scroll the list back down to view the other users.
- To undo a user delete – after deleting a user press the 'Undo User'. Only 1 undo can be done. After this panel is closed, changes cannot be undone.
- To close the panel and erase changes – press the 'close' button at the lower right side of the panel.
- To close the panel and save the changes - press the 'Accept' button on the lower right side of the panel.

User names, passwords, and access levels are stored in a binary file on the hard drive. This cannot be edited from outside of the program. After the panel closes the login panel will be open. The user pick list will be updated with any changes made on the 'Password and User Management' panel. The operator can then login as a new operator or continue under the same name.



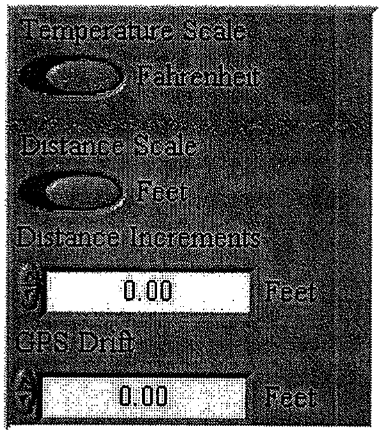

HMA Temperature Mapper Setup Panel

All controls needed to setup the data collection are configured on this panel. Operators enter project description information, select user inputs and configure serial settings and analog scaling. Information shown on the lower left side of the panel and shown below, is disabled when a user with operator access level logs into the system. The user may still view the settings for the serial port and the analog input scaling. The 'Index' slide control is not disabled so the user can scroll through the scale and offset numbers and view every channel. When logged in with higher access level then all controls are enabled and the operation of each is described in the following sections.



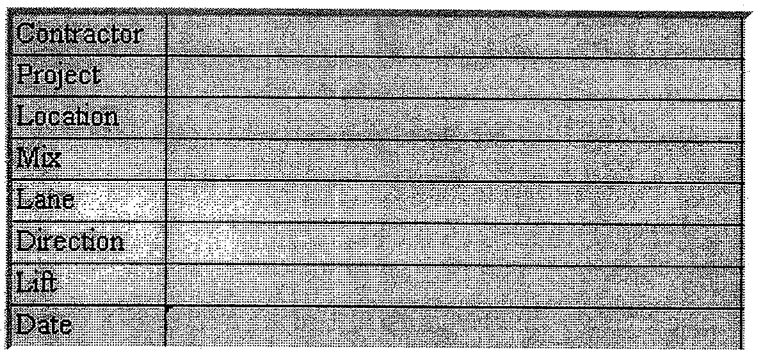
## Setup Tab

User Input



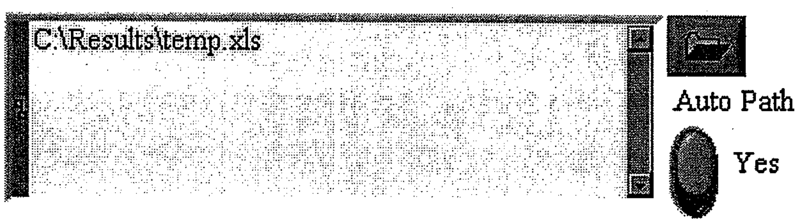

The 'User Input' control defines the scale to be used for temperature and distance as well as the distance required to signal movement and a correction factor for the GPS drift. Using the mouse the temperature scale can be changed between Fahrenheit and Celsius. The distance scale can be changed between feet and meters. The default units are Fahrenheit and feet. The 'Distance Increments' control has the value that the system uses to check for movement of the paving machine. When the GPS location indicates a change in position that exceeds this value then the software records a position change and logs the current position and temperature data to the results file. The 'GPS Drift' value is a correction factor that is subtracted from the gross pavement machine movement to compensate for the drift present in GPS positioning. Saving a project saves the values in these controls to a file so they may be recalled at a later date.

Project Description




The 'Project Description' table contains the information that is displayed on the final report and in the results file. The row headers are default, the right side of the table it blank and the information needs to be filled in before paving is began. This information is also saved and can be recalled using the save and recall project buttons. Taking advantage of this all project information can be entered at an earlier date and quickly recalled on the job site before paving begins.

Save Data to This File Name:




When the program starts the results path will display the "C:\Results\temp.xls" path. If the 'Auto Path' control to the right of the path display is set to yes then when paving begins the software will automatically generate a path for the data file. The file are stored on the 'C' drive in the results folder with the current date as a sub folder and the date and time paving began as the file name. If the 'Auto Path' is set to no then a file name will not automatically be generated. If selecting a custom data log path is desired then the browse button to the right of the path box should be used to select the results file path prior to the begin of paving.

Current User: Operator

The 'Current User' indicator displays the name of the operator currently logged into the system. To change users, exit the program and open the application again.

Access Level 0

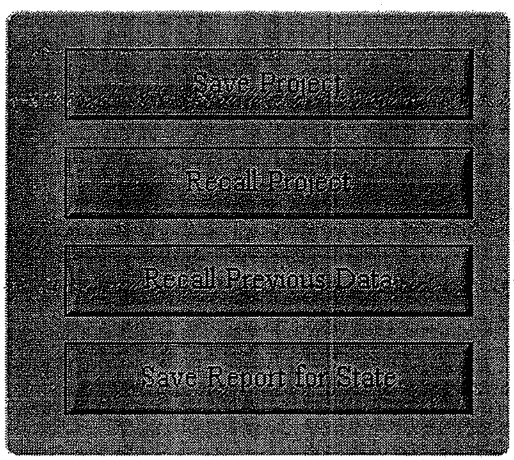
The 'Access Level' indicator displays the permission level of the user currently logged into the system. A '0' indicates operator access level, a '1' indicates administrative access level and gives access to advanced features such as channel scaling and serial settings.

Logging Interval 0.00

The 'Logging Interval' control value determines how often the system will check for paving machine movement. The software averages GPS position data over the 'Logging Interval' to minimize the error in the GPS location data. If movement is detected after the interval has elapsed then position and temperature data will be recorded in the results file.

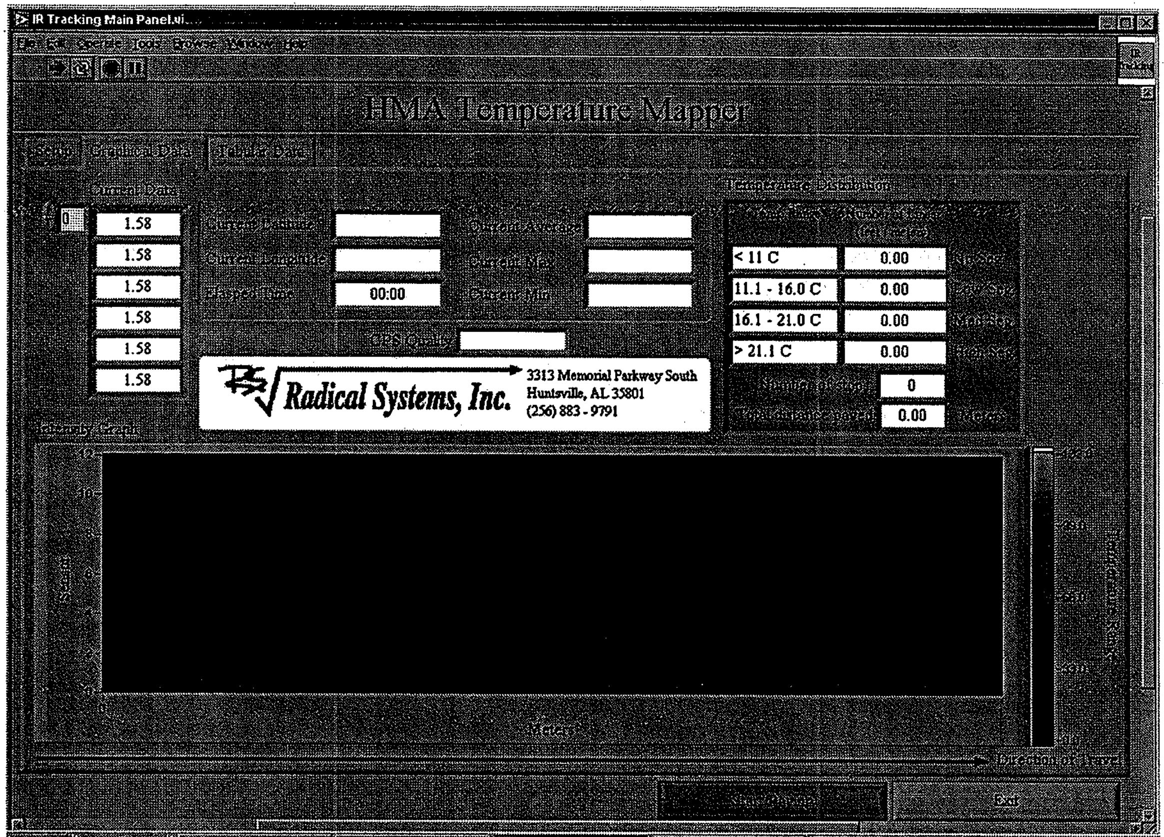
Temp Range 325 - 125 F

The 'Temperature Range' controls the range displayed on the data graph. The range does not effect the data acquisition, only the upper and lower limits on the temperature scale for the graph. The ranges will update depending on the temperature units selected. The range is saved and recalled with the save and recall project descriptions.

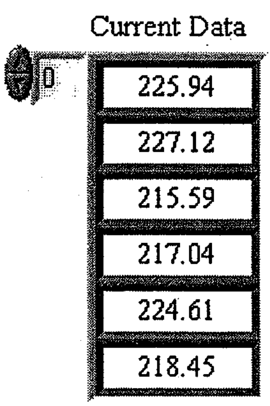



The file buttons save and recall setup data and reports. The 'Save Project' button save information from the 'User Setup', 'Project Description', and 'Temp Range' for the graph display. The 'Recall Project' button is used to select previous data files. The 'Recall Previous Data' button opens a data file and displays the tabular data and graph from the recalled data file. "Save Report for State" generates the html data report for the state agency. The state report is generated and saved in the same folder as the data was recalled from. The report may be viewed and printed using any standard web browser such as Microsoft Internet Explorer or Netscape. The report can also be opened into Microsoft Word to be edited.

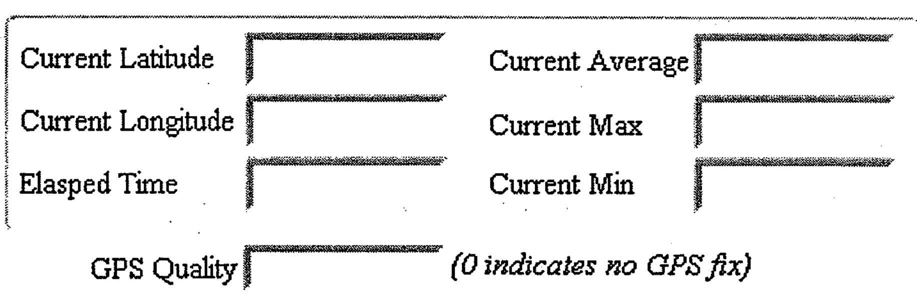
## Graphical Data




Graphical Data Tab

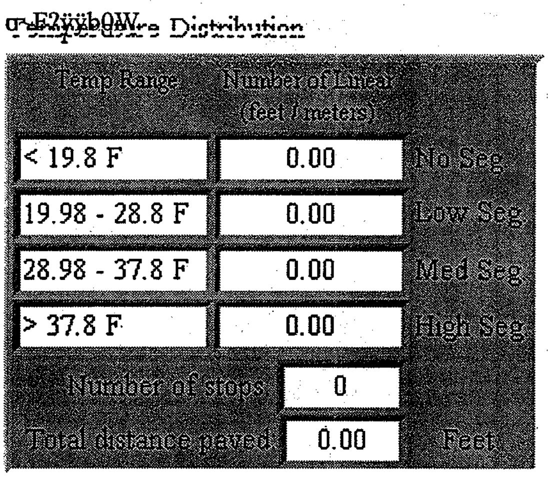



The ‘Current Data’ array displays the current data acquired by the temperature sensors in the selected scale. The index is used to scroll through the channels.




This box displays current information for the paving process includes position, time, and temperature statistics. The

'GPS Quality' indicator displays the quality of the current GPS triangulation. A "0" display indicates no satellite fix. Position data will continue to be reported, but this is the last known good position and cannot be used to determine distance traveled. A quality indicator of "1" or better is required. A "6" indicates and error condition and will clear itself as soon as a valid position fix is acquired.




The 'Temperature Distribution' panel displays the segmentation data for the current paving process. The temperature range scale is displayed in the appropriate units as defined on the setup tab. As segmentations occur the number is logged into the tally of the corresponding range. The number of stops recorded during the process and the total distance paved is displayed on the lower two indicators. A stop is defined as no movement for a period of 60 seconds. When a stop occurs the last data set is over written with the current data and a stop is recorded in the results file. Distance paved will be displayed in feet or meters depending on the units selected on the setup tab.